Martindale

Protoplasm

PROTOPLASM.

BEING THE

PRESIDENTIAL ADDRESS

DELIVERED BEFORE

THE KENDAL NATURAL HISTORY ASSOCIATION,

OCTOBER 2ND, 1913.

BY

JOSEPH A. MARTINDALE,

STAVELEY.

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I HAVE chosen for the subject of my Address to-night that peculiar and as yet, in many respects, mysterious form of matter called Protoplasm, of which are or were formed the bodies of all organisms, whether animal or vegetable, that not only now dwell upon, cover, and vivify the surface of the earth, but which, through unnumbered ages in the past, have built up rocks hundreds, nay thousands, of feet in thickness and covering millions of square miles of area throughout the world. I desire, if time permits, to speak of its origin and mode of growth, its nature and properties, and the wonderful manner in which it builds up and repairs when necessary the bodies of all organic creatures ; and how by its operation they are fruitful, multiply, and replenish the earth. For every student of Natural History,—every member of our Association—whatever branch of Natural Science he selects for his study and to which he restricts his investigations, must perforce come sooner or later to study and endeavour to understand, as far as he can, its character and properties, if he would rightly and thoroughly comprehend either the living organisms he examines or their fossil remains.

Origin.

In recent times protoplasm is nowhere found but in the cells of animals and plants, and as all the organisms existing at the present day, arose from preceding organisms of the same or similar kinds, and they in their turn, generation after generation, from others that produced them ; and as all these, both recent and ancient, live or did live in an inorganic world of the same character from the earliest times till now, we are justified in believing that this has

always been the case since vegetables and animals first appeared upon the earth. But if, rejecting revelation as some do, we would ask how did the first organism, whether plant or animal, come into being, or how was protoplasm first formed, there is nothing in the world that we can question, and any opinion that we may form can be nothing else than speculation or an unprovable and therefore unprofitable theory. The only statement we can make that seems unshakably true is that, at that early time, the temperature of the earth's surface must have been much as it is at the present day, not above that at which protoplasm coagulates and is killed, nor below that at which it cannot be formed. We may perhaps speculate further and assume that when the temperature was higher the elements that enter into the composition of protoplasm first combined, and that when the temperature was reduced, that then the compound so formed acquired the character and properties which distinguish protoplasm at the present day.

It is the general belief that organic life appeared as a new phenomenon once, and once only, when the world was young, though there are enthusiastic men who believe and say that probably it is still being spontaneously formed *de novo,* and that the aphorism 'All life from preceding life' is untrue ; but they can produce no proof that this is so, and even Prof. Schäfer, the energetic upholder of the purely materialistic view, is constrained to confess that these men are looking for it in the wrong way and in the wrong place, though he said in his Address to the British Association that "we are not precluded from admitting the possi- "bility of the formation of living from non-living substance." But possibility is not actuality nor any proof of it, and scientific men, who require from all who controvert their views the most rigorous logic and the most definite and absolute proofs of the truth of what they believe, should be the last to put forward slipshod arguments that rest on nothing surer than imagination and possibility. So far as we know, new masses of protoplasm are only produced by pre-existing protoplasm, and these new births are taking place continuously in bewildering and overwhelming numbers of instances every year.

Composition.

"Protoplasm," says Dr. Noel Paton, "is not a substance but a

"vortex of substances—a vortex constantly sucking in fresh ma-"terial and as constantly throwing off the old. To attempt to "analyse it is hopeless, but when its metabolism is destroyed—"when it is no longer protoplasm—it is found that the most "abundant solid present belongs to the group of proteids." This means that it is not a homogeneous substance, as, for instance, lime, marble, water, carbon dioxide, &c., but a mixture of proteids of different molecular composition, and that the molecules of these proteids are in constant vortical or whirling motion, similar to that of the rings which come from a smoker's pipe or lips. The attempt to analyse it is hopeless: 1st, because it is impossible to do so while it is in a so-called living state, that is, in the cells of a living organism, as the first attempt at analysis kills it, and its constitution and composition almost instantly change; 2nd, because in some cells, especially when young, it may contain little else but proteids, and in others which are older and more differentiated there are mixed with it in varying proportions cell-sap and food matters such as starch, sugar and amides; and, 3rd, because of its great complexity and the large and varying number of atoms which compose the molecules of which it is made up. Even in what might be considered the same substance it is found that when taken from different species the number of atoms in a molecule is very various. Thus, in a molecule of the hæmatoglobin taken from the blood of one animal the number of atoms was 1894, and in that taken from another there were 2304.

The elements that compose protoplasm are Carbon, Hydrogen, Oxygen, and Nitrogen, with some Sulphur and, in certain cases, Phosphorus, which in themselves and in inorganic compounds are lifeless. All plants, except fungi and parasites, take in these elements by their leaves from the air in the form of gas, and by their roots from the soil as mineral solutions. In the cells of plants the compounds absorbed are decomposed, and the elements again built up into other substances which can be made use of for growth, and this metabolism is undoubtedly brought about by chemical and electrical action. Animals, fungi, and parasites do not and cannot form food from inorganic materials; herbiverous animals eating vegetables, and those that are carnivorous devouring other animals, while some fungi and parasites feed on decaying

organic matter, and others prey upon living organisms. Thus we see that all protoplasm is derived, directly or indirectly, from and composed of inorganic elements.

Now, we are not justified in assuming that the elements change their nature and properties when absorbed by plants. They are not released from the natural forces that previously affected them, but remain after absorption as inorganic as they were before, and continue responding and subject to the same chemical, electrical, and mechanical forces as when in the earth or in the air. Neither, on the other hand, are we justified in assuming that additional powers were bestowed upon them when received into the cells of plants, or in supposing that they became living and capable of acting in any different way from that in which they could when they formed component parts of inorganic salts or gases. The German saying, '*Ohne Phosphor kein Gedank,*' is quoted by Prof. Schäfer with approval, but the atoms of Phosphorus in the brain can be no more legitimately assumed to think than those in phosphoric acid or those in the bones of the leg. Undoubtedly protoplasm is lifeless and dead matter, though it acts as no purely inorganic element or compound does or can: performs wonderful operations, builds up structures of marvellous design, repairs them when injured, provides for future wants before there is any intimation of their necessity, and finally, most wonderful of all, produces the seeds and germs of fresh individuals. And as in the inorganic kingdom neither chemistry, electricity, nor any other natural force, in itself and by itself, can cause or enable lifeless matter to do such things, it is evident that the protoplasm in the cells of organic bodies is under the influence and control of some invisible power which directs and makes use of it and the chemical and other forces to which it is subject. That power we call *Life,* which is the designer and architect of all organisms, and the efficient cause of all the wonders they perform.

Structure in Plants.

The bodies of animals and plants do not consist of a single piece or a few large masses of protoplasm, but are made up of an aggregate of minute portions which not rarely are microscopic. In plants these small masses almost invariably construct around themselves a wall of a substance called cellulose, a carbo-hydrate

of the same composition as starch but of different physical properties. In the embryonic stage of animals similar walled cells are formed, though later on there is generally no wall round the protoplasts, and the tissues of a mature animal therefore have little resemblance to those of a plant. To study the structure of protoplasm the individual cells have to be examined, and to do this thoroughly requires the use of very high powers of the microscope. Protoplasm is a colloidal form of matter, semi-fluid, but which will not pass through a membrane, or only with great difficulty, and hence it is supposed that its molecules must be comparatively very large. When examined under slight magnification it appears semi-transparent and jelly-like, and has generally a granular appearance, but there is no trace of structure, save that in all or most cells there is a denser portion or nucleus. Young cells of plants are completely filled with protoplasm which doubtless consists almost entirely of proteids. But in a very little time, as they grow larger, cell-sap brought up from the root infiltrates through the walls, and food matters are poured in from the leaves where they were elaborated, and then clear spaces called vacuoles make their appearance, which gradually coalesce till the whole internal space seems one large vacuole and the protoplasm is pushed outwards and forms a thin film round the walls. In these older cells, even when slightly magnified, other bodies known as plastids, usually of a spherical or ellipsoidal shape, are seen floating in the protoplasm, often in great numbers. They first appear around and near the nucleus, are denser than the protoplasm in which they swim, and in the interior cells of the plant and in roots are colourless, but in the cells of the leaves are coloured green by a waxy substance called chlorophyll, and in the petals of flowers are frequently red or yellow.

But when the protoplasm has first been carefully stained with hæmatoxylon, a dye prepared from logwood, or with some other staining matter, of which there are several, and the cells are submitted to examination under the highest powers of the microscope, protoplasm assumes a completely different aspect, and a decided structure, but one about which different opinions have been, and still are, held, presents itself to view. The thinner, more fluid, portion of the protoplasm *(Cytoplasm)* exhibits then the appearance

of an open network of fine threads upon which numerous granules are rather irregularly placed, the spaces between the meshes being filled with a still more watery substance. *Nucleus.*—The nucleus, on the other hand, while at rest, is occupied by what sometimes appears as a much convoluted or ravelled thread, and at other times as a very close network. On this thread or network numerous granules are affixed, and as it does not stain deeply while the granules are strongly dyed, the structure is easily made out. The network is surrounded by a fine membrane which separates it from the rest of the protoplasm, and the whole interior of the nucleus is bathed in fluid.

Structure in Animals.

Animal cells and those of fungi and parasites differ from those of ordinary vegetables in containing no plastids, and this is the reason why they cannot feed on inorganic matter but have to obtain their nutriment from substances originally elaborated by chlorophyllous plants. On the other hand all, or at all events, most animal cells contain a peculiar body called a *centrosome,* which is not possessed by the cells of the higher plants, though found in a few of the lower. The centrosome is a homogeneous body situated near the nucleus, and is generally surrounded by a clear space from which fine protoplasmic threads radiate on all sides. By those who have made an exhaustive study of this body it is regarded as a most important organ of the animal cell, and the centre of forces which cause cell division.

Huxley's Views.

Professor Huxley, in his Article on Biology in *The Encyclopædia Britannica,* wrote: "A mass of living protoplasm is simply a "molecular machine of great complexity, the total results of the "working of which, or its vital phenomena, depend on the one "hand upon its construction, and on the other, upon the energy "supplied to it; and to speak of 'vitality' as anything but the "name of a series of operations is as if one should talk of the "'horologity' of a watch." This dictum of the Professor has been quoted and applauded again and again, but though he speaks of the construction of the protoplasmic machine, he forgot for a moment that no machine ever constructed itself, that they all required a designer and a constructor, and the 'horologity' he speaks of

is centred in the man who designs and makes a watch, and not in the watch itself. We may speak of a plant, an animal, or a mass of protoplasm as a machine if we please, just as one may style the cells of plant leaves laboratories because in them chemical processes are carried on, or as we may say that the leaves themselves are the lungs of the plant because chiefly by them the plant is able to breathe ; but this is figurative language.

And if we call a plant a machine, let us recognize how much superior such a machine is to the most perfect one constructed by man, for it supplies itself automatically with the means to produce the energy necessary for its growth, development, and perfect action, and it gives birth to other machines of the same kind as itself which shall take its place when it is worn out and dead. Engineers build wonderful and powerful locomotive and other engines, but they have constantly to supply water to the boiler and coal to the furnace or their machines would stop working. Horologists construct watches and clocks, but to keep them going they have to be wound up from time to time, and electricians establish telegraphs, but their batteries have continually to be renewed ; while these and all other man-made machines wear themselves out without producing anything to take their place.

Growth.

Every botanist who has paid any attention to the physiology of the plants he studies, knows that the carbon in the molecules of the protoplasm is abstracted by composition with the oxygen breathed in through the stomates of the leaves or the lenticels of the stems, and that so necessary is this respiratory process to the very existence of all tissues and cells in every part of the organism, that even roots of plants such as mangroves growing in mud, where the supply of oxygen is not equal to their demand, send up erect branches into the air, where they form pneumathodes or air openings, and that other plants such as our native *Epilobium hirsutum, Lythrum salicaria,* and *Lycopus europæus,* in order to meet the scarcity of air in wet soil, form at the base of their stems a special white, spongy tissue for their adequate aeration. The resulting compound of carbon and oxygen is breathed out through the stomates, and thus the protoplasm loses substance and weight. Other compounds, the products of metabolism, either of no obvious

use or absolutely injurious to the plant, as acids, gums and alkaloids, are excreted in various ways, or, like raphides, are shut up in special cells. To make up this loss of substance, the plant is continually engaged in absorbing Carbon dioxide from the air, and various necessary sulphates, phosphates, and chlorides of the metals from the soil.

Intus-susception.

Professor Huxley says of this constant absorption of new matter and throwing off of the old: "The addition of molecules "to those which already existed takes place not at the surface of "the living mass but by intus-susception between the existing "molecules of the latter. If the process of disintegration and of "reconstruction which characterize life balance one another, the "size of the mass of living matter remains stationary, while if the "reconstructive process of molecular intus-susception is the more "rapid, the living body grows. But the increase of size which "constitutes growth is the result of a process of molecular intus-"susception, and therefore differs altogether from the process of "growth by accretion which may be observed in crystals, and is "effected purely by the internal addition of new matter—so that "in the well known aphorism of Linnæus the word *grow* applied "to stones signifies a totally different process from what is called "*growth* in plants and animals."

In contradiction to this Professor Schäfer says: "Should it be "contended that growth constitutes a test by which we may differ-"entiate between life and non-life, between the animate and inani-"mate creation, it must be replied that no contention can be more "fallacious. Inorganic crystals grow and multiply and reproduce "their like, given a supply of the requisite pabulum."

The passage I have quoted from Huxley was written in 1875, and of course it might be supposed that between that date and 1912 discoveries had been made in the mode of growth of crystals. If so, they must have been made very recently, for in the fifth edition of Dr. Walker's *Treatise on Physical Chemistry*, published as late as 1910, though he discusses crystals in several places, he nowhere asserts that "crystals grow by intus-susception." True he says: "It was for long supposed that no regular arrangement "of particles could subsist in liquids, the particles of which have a

"certain freedom not possessed by solids, but of late *crystalline* "*liquids* have been discovered which possess properties hitherto "only encountered in solid crystals [p. 63]. . . . It occasionally "happens that when two substances are melted together, the "liquid when cooled does not deposit one of the substances only "but both at once. This generally occurs when the two solids "crystallize in the same form. Such homogeneous solid mixtures "are often called solid solutions [p. 72], . . . and are in a sense "comparable with liquid solutions, and one crystalline substance "may be said to be dissolved in the other." [p. 212.] This is the nearest approach to what Professor Schäfer asserts that is contained in Dr. Walker's treatise, and its remoteness from any process of vegetable or animal growth needs no pointing out. The other part of his assertion, that crystals multiply and reproduce their like is even further apart from organic multiplication and reproduction.

Reproduction.

There are three forms of reproduction in plants and in the lower animals—viz. Sexual, Vegetable or Asexual, and Parthenogenetic.

1. *Sexual.*—Sexual reproduction is the nearly universal, the most perfect, and the true form of the process. In this form, the individuals of a species produce in different organs two complementary reproductive atoms, one male and the other female. Or one individual may produce only the male reproductive bodies, the female being borne on distinct individuals of the species. These two complementary bodies are designed to meet and fuse together, which action gives rise to what is known as an oospore or ovum. In these ova, which are minute microscopic nucleated pieces of protoplasm, the individuals of a new generation commence their existence. Some biologists believe that without sexual reproduction, the evolution of so many distinct and numerous species, genera, and families of either plants or animals could not have taken place. I don't know that this opinion can be accepted in full, for alteration of external circumstances seems a more potent cause of variation. But it is certainly true that when a plant—I do not know about animals—has established a number of varietal forms, any or all of them may be reproduced by the different seeds in the fruit, so that a parent, if a sexually produced individual, inherits and may distribute all the specific characters.

2. *Asexual.*—In the Asexual or Vegetative mode of giving rise to new individuals, a single cell by ordinary vegetative division produces one or more plants which in every respect are absolutely the same as the plant which gave them origin. I may illustrate the matter by pointing to the strawberry plant and the creeping buttercup, both of which send off 'runners' or aerial branches from the base of their stems, that at certain nodes send down roots into the soil and rosettes of leaves upwards. In the course of a short time the runners perish and then a number of independent individuals surround their parent. In potato plants, a 'stolon' or underground branch stem bears at its end a swollen portion or tuber which in the following year will produce a new plant in all respects the same as that which bore the tuber. In these and many other instances asexual is totally different from and inferior to sexual reproduction. When, for instance, potato tubers are planted in spring, the individuals that grow up from them are, as I have just said, identical with the plants from which the tubers were taken. On the other hand, if ripe potato seeds are sown, the young plants may reproduce any or all of the varieties of the potato that had been known, and may sometimes produce new varieties which are in men's appreciation better or worse than the old. Thus by asexual reproduction the individual only is reproduced, and by the sexual mode the species.

3. *Parthenogenesis.*—The Parthenogenetic form of reproduction occurs in a considerable number of the species of lower animals, but not, so far as I know, in any of the higher. It takes place in bees, wasps, silk-worm moths, sea-urchins, and in many species of other families. In plants it is known among the Cryptogamia, in a species of Stonewort, and in several species of mosses. A few cases also are known among Flowering plants, as in one of the Cudweeds, and in the annual Dog's Mercury. In these cases the female ovum, without fusion with the complementary male body, proceeds to divide and develop into a new individual. What is its cause and its nature are not yet by any means understood, and many experiments have been made to throw light upon the matter. Unfertilized ova of several sea-urchins have been variously treated. In some of the experiments the ova were shaken to detach and eject the nucleus; in others enucleated portions of the ova were

separated by cutting ; and in a third class of trials, a diluted solution of a lithium or a magnesium salt was added to some sea-water, in which the ova were placed for a time and then returned to their usual medium. In most cases all these ova proceeded to develop, even those that had been mutilated ; but, so far as I know, not in any instance did development proceed further than the larval form, whilst others stopped short of that.

Professor Schäfer makes use of these experiments, which evidently seem nothing more than instances of an artificially-produced parthenogenesis, to proclaim that the doctrine of "vitalism has "not only had its foundations undermined, but most of the superstructure has toppled over." As usual, however, in making his comparisons he exaggerates matters on the materialistic side, for none of the treated ova, as far as I can learn, ever reached maturity, and even if they had, they would be nothing more than cases of parthenogenesis.

Development of the Organic body.

As soon as the fusion between the two complementary reproductive bodies has been completed, the resulting fertilized ovum or egg, in all organisms alike, begins to develop. It surrounds itself with a wall, probably of cellulose, which must have been formed by some catalytic chemical process from the protoplasm. We see, then, a simple nucleated cell which at once divides into two halves by building a wall across its middle. These two cells each divide again in the same way into four, and the four into eight, and these again and again till a considerable tissue of cells has been formed. The process in its early stages is essentially the same in all organisms, whether animal or plant, but the arrangement of the cells and their position in regard to each other are very various. As each new division of cells is made, there arises a certain differentiation among them which probably is caused by an alteration in the character of their protoplasm. One thing is certain, to one set of cells one function is assigned, and to others a different function. In plants some cells are deputed to give rise to the root, others to the stem, and others again to the leaves ; and each set of cells, with a certain function to perform, occupies the exact place which the organ produced must occupy in the developed body, in order that it may perform its work.

Cell Division.

The manner in which the division of cells is brought about and the dividing-wall built is wonderful in the extreme. It is preceded by the division of the nucleus, and also, in animal cells by that of the centrosome. The whole complex process has been studied in the cells of numerous plants and animals, and is found to take place exactly in the same manner in all of them.

1. The nucleus first increases in size, the filmy wall surrounding it disappears, the ravelled thread opens its coils, and in animals the centrosome divides in two, one of the halves migrating to the opposite side of the developing nucleus.

2. Secondly, the nuclear thread splits up into a certain number of equal pieces called chromosomes, the number of which varies considerably in different species, but remains constant in the same one. These pieces shorten themselves and grow thicker, and the coloured granules attached to them are thus brought into more equal distance from each other.

3. Thirdly, a number of fine threads suddenly make their appearance, which form a sort of spindle that in animal cells lies between the two centrosomes at the opposite sides of the nucleus. The same kind of spindle is formed in plants, and though they have no visible centrosomes, lies in the same direction as if such were present.

4. Fourthly, the chromosomes move towards the equator or broadest part of the spindle, each along one of the spindle threads, and as they go all of them divide lengthwise, together with all the coloured granules along their length, so that each half of the threads of the chromosomes receives an equal number of half-granules.

5. In the fifth place, one half of each longitudinally-divided chromosome, with its attached half-granules, separates from the other, and two half-nuclei are formed consisting of the same number of half-chromosomes. Each of these loops itself in the shape of the letter V, and with their points turned towards the centrosomes, the two sets proceed in opposite directions along the spindle threads to the poles or narrow end of the spindle. There the chromosomes of each half-nucleus unite again and form a continuous thread which ravels itself up as in the original nucleus before it prepared to divide. In this elaborate way two equal nuclei are

formed from the original one, and by the manner in which the chromosomes divide they consist of an equal number of coloured granules.

6. And now the sixth and last phase of the complicated procedure takes place. Along the equator of the spindle, and thus midway between the two new nuclei, minute particles of matter suddenly become visible between the spindle threads; these increase in size and in number, and build across the middle of the dividing cell a wall which always remains pierced with microscopically minute holes, through which protoplasmic threads keep up a means of communication between the severed halves, which are now complete and whole cells, sharing the nucleus and the protoplasm of the mother cell equally between them. The threads of protoplasm running through the wall may be regarded as rudimentary nerves, just as the conducting tissue in the stem of a moss is rudimentary xylem and phloem. From many examinations in a number of plants it is now certainly known that by these minute threads each cell of a plant is in direct or indirect communication with all the rest, and we are thus in a position to understand movements formerly considered mysterious, such as when one pinnule of a leaf of the sensitive plant is touched the whole leaf should at once proceed to fold up and hang down on its petiole.

Professor Schäfer would compare this extremely complicated but thoroughly satisfactory mode of division, which results in the two new nuclei being formed, each having an exact share of the original nuclear thread and equal halves of each coloured granule —he would compare it with the molecular dance of some particles of carbon suspended in a solution of salt. He says: "Even so "complex a process as the division of a cell nucleus by *karyokinesis*, "as a preliminary to the multiplication of the cell by division—a "phenomenon which would *prima facie* have seemed and has com-"monly been regarded as a distinctive manifestation of the life of "the cell—can be imitated with solutions of a simple inorganic salt, "such as chloride of sodium, containing a suspension of carbon par-"ticles; which arrange and rearrange themselves under the influence "of the movements of the electrolytes in a manner indistinguishable "from that adopted by the particles of chromatin in a dividing "nucleus." But there is not even similarity between the two

things, and they are abundantly distinguishable. The chromosomes divide longitudinally and so do the coloured granules, that both half-nuclei may be exactly the same. The chromosomes —which the Professor seems to mistake for the coloured granules —do not dance about like the particles of carbon when butted against by the electrolytes, but proceed in an orderly and predetermined path towards the place where, as the components of the new nuclei, they must take up their position.

The Professor is rashly daring, for none but a rash man could ever have thought of propounding a comparison so thoroughly inept.

Conclusion.

I have now placed before you some account, inadequate enough, of the origin, composition, structure, and activities of protoplasm, and tried to show in what general manner it builds the bodies of plants and animals. What then is protoplasm as we know it in the world of the present day? We may, I believe, confidently say that it is a complex, materialistic and lifeless compound, formed and maintained by that power we call Life, which constantly controls and directs it; and, making use of all the chemical affinities and electric adaptabilities of its elements, brings about all its activities, designs the structures it builds, and enables it by a power of variation to provide against and ward off the physical dangers which may threaten it. And what is Life? Its essential nature no one knows; we only recognize it by what it performs, and by the purpose that underlies and guides all it actions, by which it is abundantly distinguished from any natural force—chemical, electrical, mechanical, or other—all of which Life dominates and compels to serve its ends.

JOSEPH A. MARTINDALE.

J. S. Jowett, Printer, 3 Windermere Road, Kendal.